22-A-8

A77.32: S-10

ISSN 0193-2853

Low-Dose Irradiation as a Treatment for Grapefruit and Mangoes Infested With Caribbean Fruit Fly Larvae

COMPLETED

12

U.S. Department of Agriculture
Agricultural Research Service ← Formerly Science & Education Administration
Agricultural Research Results • ARR-S-10/October 1981

I

The authors acknowledge the assistance of the following individuals and organizations who cooperated in these experiments: Ari Brynjolfsson and Fred Heiligman, Radiation Preservation of Food Division, Food Engineering Laboratory, U.S. Army Natick Research and Development Command, Natick, Mass.; Jack S. Sivinski and Jerry R. Brandon, Applied Biology and Isotope Utilization Division, Sandia Laboratories, Albuquerque, N. Mex.; Martin A. Welt and Robert Buckley, Radiation Technology, Inc., Rockaway, N.J.; Randall Cubbedge, U.S. Horticultural Research Laboratory, Agricultural Research Service, Orlando, Fla.; and William Reeder, Subtropical Horticulture Research Unit, Agricultural Research Service, Miami, Fla. The grapefruit used in these experiments were supplied by the Florida Citrus Commission; the mangoes were supplied by the Mango Forum.

This publication is available from the Subtropical Horticulture Research Unit, 13601 Old Cutler Rd., Miami, Fla. 33158.

On June 17, 1981, the Secretary of Agriculture abolished the Science and Education Administration, formerly the publisher of this series, and reestablished the four agencies (Agricultural Research Service, Cooperative State Research Service, Extension Service, and National Agricultural Library) out of which SEA had been organized in 1978. This series will continue under the imprint of the Agricultural Research Service (Southern Region).

Agricultural Research Service, Agricultural Research Results, Southern Series, No. 10, October 1981.

Published by Agricultural Research Service (Southern Region), U.S. Department of Agriculture, P.O. Box 53326, New Orleans, La. 70153.

BEST DOCUMENT AVAILABLE

CONTENTS

	Page
Abstract	1
Introduction	1
Research	2
Caribbean fruit fly larvae	2
Grapefruit	2
Mangoes	5
Discussion and recommendations	6
References	8

ILLUSTRATIONS

Fig.		
1.	Irradiation injury to grapefruit	3
2.	Irradiation injury to mangoes	6

TABLES

1.	Survival of Caribbean fruit flies from infested grapefruit irradiated at various dosages	2
2.	Injury to grapefruit exposed to irradiation from various sources	4
3.	Taste-panel evaluation of grapefruit exposed to irradiation from various sources	4
4.	Analysis of juice from grapefruit exposed to irradiation from various sources	5
5.	Injury to 'Keitt' mangoes exposed to gamma radiation	6

BEST DOCUMENT AVAILABLE

Low-Dose Irradiation as a Treatment for Grapefruit and Mangoes Infested With Caribbean Fruit Fly Larvae

By A. K. Burditt, Jr.,[1] M. G. Moshonas,[2] T. T. Hatton,[1] D. H. Spalding,[3] D. L. von Windeguth,[1] and P. E. Shaw[2]

ABSTRACT

Research is reported on use of irradiation (gamma rays and X-rays) as a possible treatment for Florida-grown grapefruit and mangoes infested by larvae of the Caribbean fruit fly, *Anastrepha suspensa* (Loew). Treatment of fruit at dosages of 10 to 20 krads would prevent adult flies developing from infested fruit. Grapefruit treated at dosages of 25 to 60 krads had increased skin pitting, scald, and decay. For some treatments the taste of pasteurized juice from irradiated fruit differed significantly from that of controls, and the taste of fresh juice and sections and the aroma of peel oil from fruit treated with X-rays differed significantly from that of controls. There was a slight reduction in the vitamin C content of irradiated fruit. Beta-pinene was absent from fruit irradiated with 50 krads. Irradiated mangoes had surface-blemish injury that was related to dosage. Index terms: *Anastrepha suspensa* (Loew), gamma radiation, grapefruit, irradiation, mangoes, X-rays.

INTRODUCTION

Grapefruit and mangoes grown in Florida may be infested with the larvae of the Caribbean fruit fly, *Anastrepha suspensa* (Loew). To prevent the spread of the fly, these fruits must be fumigated with ethylene dibromide before being shipped to Arizona, California, Hawaii, Texas, Japan, and some other areas (U.S. Code of Federal Quarantine Regulations). Gamma irradiation is being considered as a replacement for fumigation.

Balock et. al. (1956) proposed use of gamma irradiation as a treatment for fruit subject to quarantine because of its susceptibility to fruit fly infestations. Since then, considerable research has been done on several species of fruit flies in various experimental settings (Balock et al. 1963 and 1966, Benschoter and Telich 1964, Macfarlane 1966, Hossain and Hamid 1968, Shipp and Osborn 1968, Bughio et al. 1969, Cavalloro and Delrio 1971, Seo et al. 1973, Thomas and Rahalkar 1975). This research has shown that fruit flies are generally adversely affected by low doses of gamma radi-

[1]Entomologist, Subtropical Horticulture Research Unit, Agricultural Research Service, U.S. Department of Agriculture, 13601 Old Cutler Rd., Miami, Fla. 33158. (Burditt's present address is Yakima Agricultural Research Laboratory, Yakima, Wash. 98902.)

[2]Chemist, Citrus & Subtropical Products Laboratory, Agricultural Research Service, U.S. Department of Agriculture, P.O. Box 1909, Winter Haven, Fla. 33880.

[3]Horticulturist, U.S. Horticulture Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 2120 Camden Rd., Orlando, Fla. 32803.

[4]Plant pathologist, Subtropical Horticulture Research Unit.

BEST DOCUMENT AVAILABLE

ation; even if irradiation does not kill the eggs or larvae, it prevents the insect from developing to the adult stage or results in the development of adults incapable of reproducing. The research has also shown that fruit flies vary in susceptibility to gamma radiation. Our first concern, then, was the effects of various doses of radiation specifically on the Caribbean fruit fly.

Our second question concerned the effects of irradiation on grapefruit and mangoes themselves. Previous work with mangoes and other fruits (Beraha et al. 1959, Hatton et al. 1961, Dennison et al. 1966, Dollar et al. 1971) suggested that radiation effects, not necessarily adverse, could be expected.

RESEARCH

Research was undertaken to determine what, if any, adverse effects would result from irradiation of grapefruit and mangoes, and to confirm that dosages of irradiation used for other species of fruit flies would give quarantine security (99.9968% mortality—Baker 1939) for fruit infested with larvae of the Caribbean fruit fly. Since the cobalt-60 gamma irradiator at our Miami laboratory only had the capacity for three or four grapefruit at a time, arrangements were made with Radiation Preservation of Food Division, Food Engineering Laboratory, U.S. Army Natick Research and Development Command, Natick, Mass., and with the Applied Biology and Isotope Utilization Division, Sandia Laboratories, Albuquerque, N. Mex., for treatment of the large quantities of fruit used in these tests. One lot of mangoes was treated at Radiation Technology, Inc., Rockaway, N.J.

Caribbean Fruit Fly Larvae

To test the effect of irradiation on the survival of Caribbean fruit fly larvae, grapefruit obtained from various packinghouses and groves in the Indian River area of Florida were placed for about a week in infestation cages containing several thousand sexually mature flies. The infested fruit were held for another week and then were exposed, two or three at a time, to gamma radiation from a cobalt-60 source. The declining dose rate of the cobalt-60 source ranged from 1.238 to 1.158 krads per minute during the period of these tests. The treated fruit were held for 5 weeks more to permit larvae to mature and pupate, and the pupae were watched for emergence of adults.

No adult flies developed from eggs and larvae present in fruit irradiated at 10 krads and above (table 1).

Grapefruit

'Marsh' seedless grapefruit (the variety currently being shipped to Japan) were trucked from packinghouses in the Indian River area of Florida to the Subtropical Horticulture Research Unit in Miami, where they were randomized and placed in fiberboard shipping cartons. On May 7, 1979, 100 cartons, each containing about 40 pounds of fruit, were shipped by air to Logan Airport, Boston, Mass. From there they were taken by truck to the nearby Food Engineering Laboratory at Natick for irradiation. Since the cobalt-60 unit was not operational when the fruit arrived, it was stored at 10° C until it could be treated. On May 29, 30 cartons of fruit were exposed to 25 krads of X-rays, using an electron beam with a tungsten converter from the LINAC (linear accelerator) source. Another 30 cartons were exposed to 50 krads, and a like number were untreated. Following treatment, the fruit was sent by air to the U.S. Horticultural Research Laboratory in Orlando, Fla., for observation of phytotoxic effects; some fruit was sent to the Citrus & Subtropical Products Laboratory at Winter Haven, Fla., for chemical analysis and quality evaluation.

Table 1.—Survival of Caribbean fruit flies from infested grapefruit irradiated at various dosages

Gamma-ray dosage (krads)	Estimated population of eggs and larvae treated[1]	Survivors (number)	
		Pupae	Adults
2.50	1,240	1,285	0
3.75	596	259	0
5.00	585	170	0
7.50	325	10	3
10.00	831	193	0
12.50	1,387	274	0
15.00	1,012	64	0
20.00	766	15	0
25.00	720	46	0
30.00	183	0	0

[1]Theoretical number extrapolated from pupae recovered from equivalent number of control fruit. (Control and treated fruit were randomly selected from a total load of fruit exposed to a high population of gravid female *A. suspensa* in an outdoor infestation cage.)

BEST DOCUMENT AVAILABLE

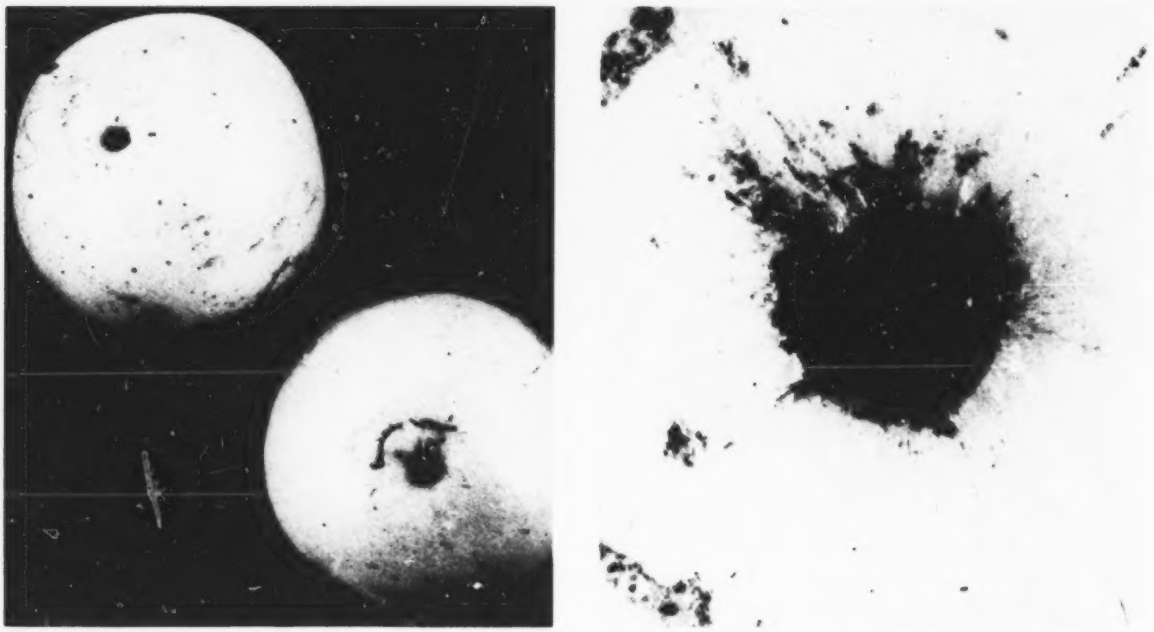

FIGURE 1.—Irradiation injury to grapefruit. At all doses, irradiation caused black-colored necrosis of the button (left; enlarged at right). The camera did not capture the pitting and scald of the rind, which were superficial and slight, often occurring together. Pitting appeared as pinpoint depressions with normal peel color. Scald appeared as a faint bronze discoloration covering most of the fruit.

Additional 'Marsh' grapefruit obtained from the Indian River area were randomized at Miami, and on May 18, 1979, were shipped by air to Sandia Laboratories, Albuquerque, N. Mex., for treatment with gamma radiation from either a cobalt-60 or a cesium-137 source. Thirty cartons of fruit were exposed to either 25 or 50 krads from cobalt-60 or to 50 krads from cesium-137 or were used as controls. The 120 cartons were returned to Miami by air on May 27, and taken by truck to Winter Haven and Orlando for analysis and observation, as above.

More 'Marsh' seedless grapefruit obtained from the Indian River area on November 27, 1979, were sent by air to the Sandia Laboratories on November 28, irradiated with 30 or 60 krads, and shipped from Albuquerque on November 30 to Orlando, arriving December 1.

At Orlando, the first two test lots of fruit (late season) were held at 10° C and the last test lot (early season) was held at 15° C for 4 weeks to simulate shipment to Japan (Lutz and Hardenburg 1968) and at 21° C for 1 week to simulate marketing conditions; during this time the grapefruit were observed for peel injury, softening, and decay. The treated fruit had a higher incidence of scald and decay, which was more pronounced after the fruit had been held at 21° C for 1 week (table 2). The button of the treated fruit had a black necrotic injury (fig. 1).

At Winter Haven, various treated grapefruit products were sampled by an experienced taste panel using either a triangle or paired comparison test, and the composition of the juice was analyzed. To the taste panel, some of the irradiated-grapefruit products tasted or smelled different from their unirradiated counterparts (table 3). All the pasteurized juice samples except those from the 25-krad X-ray treatment and the 30-krad cesium treatment tasted different. Fresh fruit sections treated with X-rays had detectable taste differences. All products from the 50-krad X-ray treatment tasted or smelled different. Otherwise, there were no differences in the taste or aroma between treated and untreated grapefruit. As for the composition of fresh juice, irradiation reduced vitamin C content by 0.6% to 7.5% but did not seem to affect the oil and acid content significantly (table 4).

Also at Winter Haven, Moshonas and Shaw

BEST DOCUMENT AVAILABLE

Table 2.—Injury to grapefruit exposed to irradiation from various sources

[Percent]

Treatment	Upon arrival[1]	After 4 weeks storage[2]			Plus 1 week at 21° C[3]		
		Pitting	Scald	Decay	Pitting	Scald	Decay
Natick:[4]							
Control	0.0	0.0	0.0	1.9	0.6	0.0	7.5
X-ray:							
25 krads	1.3	1.3	6.9	5.6	.6	5.0	15.6
50 krads	1.3	1.3	8.1	1.3	1.3	4.4	10.0
Sandia:[5]							
Control	.8	.8 b	0	6.3	.8	0	18.3 b
Cobalt-60:							
25 krads	.8	2.4 b	8.0	12.8	1.6	2.4	32.0 ab
50 krads	7.4	12.3 b	0	18.1	4.9	0	55.7 a
Cesium-137,							
50 krads	0	.8 b	0	13.6	1.6	5.6	33.6 ab
Sandia:[6]							
Control	0	0	0	10.7	0	0	17.3
Cesium-137:							
30 krads	0	0	4.6	11.7	0	3.6	17.1
60 krads	0	0	7.5	13.5	0	2.5	21.5

[1]Pitting injury shown when fruit were received at Orlando after irradiation, prior to storage.

[2]Late-season fruit stored at 10° C, early-season fruit at 15° C.

[3]Some areas classified as pitting and scald injury after 4 weeks at 10° C subsequently developed decay after a week at 21° C and could no longer be evaluated for pitting and scald. Treated fruit were softer and more senescent in appearance than control fruit. Decay consisted mostly of rot caused by green mold, *Penicillium digitatium*, which prevails when injury is present.

[4]Each value is the means of 5 cartons of late-season fruit, a total of about 160 fruits.

[5]Each value is the means of 4 cartons of late-season fruit, a total of about 125 fruits. Mean separation by Duncan's multiple-range test; values in a column followed by the same letter are not significantly different at the 5% level.

[6]Each value is the mean of 5 cartons of early-season fruit, a total of about 200 fruits.

Table 3.—Taste-panel evaluation of grapefruit exposed to irradiation from various sources

Treatment	Difference between treated and untreated fruit[1]			
	Taste of—			Peel-oil aroma
	Fresh juice	Pasteurized juice	Fresh sections	
Natick, X-ray:				
25 krads	ns	ns	*	ns
50 krads	***	**	+	*
Sandia:[2]				
Cobalt-60:				
25 krads	ns	**	(3)	ns
50 krads	ns	**	ns	ns
Cesium-137, 50 krads	ns	***	ns	ns
Sandia:[4]				
Cesium-137:				
30 krads	ns	ns	ns	ns
60 krads	ns	*	ns	ns

[1]Taste-panel perceptions of differences between irradiated and untreated fruit were significant at the 10% level (+), 5% level (*), 1% level (**), or 0.1% level (***), or not significant (ns) (chi-square).

[2]Late season fruit. [3]Not tested. [4]Early-season fruit.

Source: Moshonas and Shaw (paper in progress).

BEST DOCUMENT AVAILABLE

Table 4.—Analysis of juice from grapefruit exposed to irradiation from various sources

Treatment	Composition of juice					
	Vitamin C		Oil	Acid		
	mg/100 ml	Reduction[1] (%)	(%)	Brix	mg/100 ml	Brix/acid
Natick:						
Control	41.36	.....	0.006	9.5	0.98	9.69
X-ray:						
25 krads	38.25	7.5	.005	9.3	.93	10.00
50 krads	39.04	5.6	.005	9.3	.92	10.11
Sandia:[2]						
Control	36.48	.....	.006	9.8	.80	12.25
Cobalt-60:						
25 krads	36.25	.6	.006	9.9	.78	12.69
50 krads	34.55	5.3	.007	9.4	.80	11.75
Cesium-137, 50 krads	34.85	4.5	.006	9.7	.75	12.93
Sandia:[3]						
Control	49.51	.....	.006	9.1	1.05	8.7
Cesium-137:						
30 krads	47.71	3.6	.005	9.1	1.05	8.7
60 krads	47.90	3.3	.007	9.1	1.00	9.1

[1]Percent reduction from control sample.
[2]Late-season fruit.
[3]Early-season fruit.

Source: Moshonas and Shaw (paper in progress).

(their paper is in progress) analyzed 19 oils from the peel of irradiated and untreated grapefruit. No significant quantitative or qualitative differences in major volatile constituents were found. The compound 6,7-dimethoxycoumarin, found by Riov (1971) in the extracts of the flavedo (external colored peel layers) of grapefruit irradiated with gamma rays at 300 and 400 krads, was not found in any peel oil from our irradiated samples. Beta-pinene was found in the peel oil from fruit treated at 25 krads and from untreated fruit but not in the oil from fruit treated at 50 krads.

Mangoes

On July 23, 1979, mature green, just-picked 'Tommy Atkins' mangoes were obtained from a Miami packer, randomized, and sent by mail to the Sandia Laboratories for irradiation. They were irradiated with 35, 50, 75, or 150 krads from cesium-137 or 75 krads from cobalt-60 on July 26 or 27 and returned to Miami by mail, arriving on August 1. They were held at the Miami laboratory for observation.

The 'Tommy Atkins' mangoes shipped to and from New Mexico by mail were held at ambient temperatures for 10 days. When the fruit arrived in Miami, 55% of the untreated mangoes showed decay and breakdown because of these adverse shipping and storage conditions. Nevertheless, decay attributable to irradiation could be differentiated and ranged from 45.0% for fruit exposed to 150 krads using cesium-137 to 76.8% for fruit exposed to 75 krads using cobalt-60. The fruit treated at these two levels also had 33.4% and 15.0% scaldlike browning of the skin, respectively.

On August 6, mature, green, just-harvested 'Keitt' mangoes were obtained from the same source and randomized. A portion of the fruit was shipped by air to the Sandia Laboratories for irradiation at 35, 50, 75, or 150 krads from cesium-137 or 75 krads from cobalt-60. The fruit was returned to Miami by air on August 9 and held for observation. On August 7, the remainder of the 'Keitt' mangoes was shipped by air to Radiation Technology, Inc., Rockaway, N.J., for irradiation at 25, 50, 75, or 150 krads from cobalt-60. They were returned to Miami by air on August 8 and held for observation. Both shipments of mangoes were held at 21° C for 20 days and inspected for injury, softening, and decay. After 16 to 20 days they were

BEST DOCUMENT AVAILABLE

FIGURE 2.—Irradiation injury to mangoes. At left is an untreated fruit. The center fruit, with slightly dark lenticels, was treated at 75 krads. Injury was related to dosage. The fruit at right with dark, sunken areas, was treated at 150 krads.

sampled for taste in a paired comparison test by untrained station personnel.

Irradiation caused dark, sunken areas in the surface of the skin of 'Keitt' mangoes (fig. 2). The degree of injury was directly related to the irradiation dosage (table 5). The injured areas appeared more susceptible to subsequent decay, especially anthracnose. In a paired taste panel test at Miami, 12 panelists preferred irradiated fruit, 11 preferred control fruit, and 10 had no preference.

Table 5.—Injury to 'Keitt' mangoes exposed to gamma radiation

[Percentage of fruit with dark sunken areas 6 days after irradiation]

Dosage (krads)	Irradiation source		
	Sandia		Radiation Technology (cobalt-60)
	Cesium-137	Cobalt-60	
0	0	0	0
25	(-)	(-)	15
35	22	(-)	(-)
50	31	(-)	26
75	33	13	29
150	48	(-)	69

Control.
Dosage not tested

DISCUSSION AND RECOMMENDATIONS

Our research, as well as that conducted elsewhere during the past 25 years, has demonstrated the potential of irradiation as a quarantine treatment. Although these studies have differed in details, the concensus has been that exposure of commodities infested with fruit flies to between 2 and 25 krads will prevent adults from emerging from irradiated eggs, larvae, or 1- to 3-day-old pupae. For instance, in Hawaii, exposure of eggs, larvae, and 1- to 3-day-old pupae of the oriental fruit fly, *Dacus dorsalis* Hendel; the melon fly, *D. cucurbitae* Coquillett; and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), to 6.5 krads of gamma radiation from a cobalt-60 source prevented 95% emergence of adults (Balock et al. 1963). Low doses of radiation (less than 10 krads) did not result in immediate kill of eggs or larvae but did prevent emergence of adults. Irradiated eggs did not hatch if they were less than 50% developed. Once they had passed this point, however, the eggs continued to develop and hatched. After the eggs had hatched, the larvae continued to develop but usually did not reach maturity or form puparia. Fruit fly larvae irradiated at less than 10 krads continued to feed and eventually reached maturity and formed puparia, but they were unable to become adult.

An increase in dosage of from 59% to 78% was required to achieve these results if eggs or larvae were irradiated in water or in nitrogen or carbon dioxide. The probit 9 security (Baker 1939) required for quarantine security was estimated to be 20.6 krads for the oriental fruit fly infesting papayas (Balock et al. 1966). Balock et al. (1963) also showed that the melon fly was slightly more resistant to the effects of gamma radiation than the oriental fruit fly and that the Mediterranean fruit fly was most susceptible of the three species.

Research elsewhere has produced similar results. Benschoter and Telich (1964) showed that exposure of 1-day-old eggs of the Mexican fruit fly, *Anastrepha ludens* (Loew), to gamma radiation from a cobalt teletherapy unit at 2,000 roentgens resulted in 99.9% mortality of the eggs, and exposure of mature larvae to 1,500 roentgens prevented 99.523% emergence of adult flies. Thomas and Rahalkar (1975) reported that larvae of oriental fruit flies and melon flies or larvae developing from eggs exposed to 15 or 25 krads were sluggish and had a reduced growth rate when compared to those from untreated eggs or larvae. No adults emerged from any of the treated eggs or larvae or from 3- to 4-day-old irradiated pupae. Macfarlane (1966) found that, for the Queensland fruit fly, *Dacus* (*Strumeta*) *tryoni* (Froggatt), a dose of 5 krads prevented adult emergence from irradiated eggs and larvae. Shipp and Osborne (1968) found that nearly all of the adults that might emerge from any Queensland fruit fly pupae treated at this dosage would be sterile; they suggested a dose of 10 krads, however, to provide an adequate quarantine treatment. Cavalloro and Delrio (1971) found that there were no significant differences in the effect of radiation on the larvae of the olive fly, *Dacus oleae* Gmelin, and the Mediterranean fruit fly, but the eggs and older pupae of the olive fly were slightly more resistant to radiation than were comparable stages of the Mediterranean fruit fly. Three-day-old pupae of the olive fly were slightly more susceptible, possibly because of differences in the stage of development. For both species radiation delayed hatching and reduced emergence, survival, and mating of adults; delayed growth of larvae irradiated at 1 day old; and, at higher doses, reduced larval weight and pupation. They found that irradiating eggs, larvae, or 3-day-old pupae at 2 krads prevented any emerged adults from reproducing. Bughio at al. (1969) found that 4- to 5-hour-old eggs of *Dacus zonatus* (Saunders) exposed to 4 krads did not hatch and that no normal adults emerged from older eggs irradiated at this dose; that at 12 krads, the highest dose tested, hatch of older eggs was reduced but not prevented; and that irradiation of eggs extended the larval period and reduced pupation. When Hossain and Hamid (1968) irradiated older larvae of the mango fruit fly, *Cheatodacus ferrugienus* Fabricius, at 2 to 5 krads, no adults emerged, but at 1 krad adults emerged sooner than from the controls.

Other species of insects of quarantine importance may be eliminated from infested produce by using gamma irradiation. One of these, the mango weevil, *Cryptorhynchus mangiferae* (Fabricius), is found in most mango-growing areas of the world except Central America, Mexico, and the mainland United States. In Hawaii Seo et al. (1974) demonstrated that gamma radiation of infested mangoes at dosages of 20.6 or 32.9 krads prevented eggs or larvae from producing adults or resulted in adult weevils that could not reproduce. They found that adult females exposed to 10 or 20 krads died without laying eggs, longevity being related to dose. Thomas (1975) reported that treatment of infested mangoes at 50 krads gave 100% mortality of larvae and pupae and 75 krads prevented adults from escaping from the seedpod. Recent studies (Burditt, unpublished) have shown that exposure of codling moth larvae, *Laspeyresia* (*Cydia*) *pomonella* (Linnaeus), in infested apples to 8 krads resulted in only a few adults emerging, and they were malformed.

While research has established that irradiation is a potential treatment for commodities infested with insects, research on the tolerance of fresh fruit to irradiation has not been as promising, especially as regards citrus and mangoes. Our studies have indicated that adverse effects result at the relatively low doses required for quarantine treatments, as well as at the higher doses used by others. Dennison et al. (1966) found that irradiation at 100 krads induced peel injury in 'Pineapple' and 'Valencia' oranges, 'Duncan' grapefruit, and Temples. This was associated with storage temperature and duration and use of diphenyl. Beraha et al. (1959) reported skin discoloration and softening of lemons irradiated at dosages of 500,000 rep

BEST DOCUMENT AVAILABLE

for control of *Penicillum digitatum* and held at 75° F. They indicated that 200,000 rep was optimal for extension of shelf life of 'Navel' oranges inoculated with *P. italicum*. Sreenivasan et al. (1971) reported that mangoes irradiated under a nitrogen atmosphere withstood doses as high as 200 krads, while the skin of those treated in air turned black. Pable et al. (1971) found that beta-carotene and ascorbic acid were higher in mangoes irradiated at 60 krads and stored 10 to 13 days at 30° C than in unirradiated fruit. Hatton et al. (1961) found that treatment of 'Irwin' and 'Sensation' mangoes at 25 krads retarded ripening and impaired flavor.

Additional research is needed to determine the significance of adverse effects on commodities that have been irradiated. There is a wealth of information on doses in excess of 100 krads, but little at less than this amount. This research should include experiments to evaluate a full range of postharvest handling and storage conditions such as wax treatment, controlled-atmosphere storage, cold storage, and simulated shipments. Data should be collected on the possible effects of low-dose irradiation on decay, weight loss, firmness, color, specific gravity, soluble solids, ripening, chemical composition, and so forth. Also, studies are needed to determine if sensitive commodities could be irradiated in an atmosphere other than air, such as nitrogen, with fewer adverse effects.

Research has demonstrated that the dose of gamma irradiation required for a fruit fly quarantine treatment could be less than 25 krads. But the necessity of treating large quantities of fruit and the desirability of treating already packaged fruit may mean that, to give a minimum dose to all fruit, the maximum dose might have to be double or triple the minimum. Seo (Burditt and Seo 1971, Seo et al. 1973), using papayas infested with larvae of the oriental fruit fly, the Mediterranean fruit fly, and the melon fly, found that bulk density affected the dose required for quarantine security, 21.4, 25.2, 29.1 krads being required for bulk densities of 0.30, 0.35, and 0.40 g/cm^3, respectively. In the later study, fruits were placed in fiberboard cartons and irradiated in either a large research radiator or a quasicommercial developmental unit. The minimum dosage required for quarantine security had to be increased to compensate for absorption by the packaging material. And there are related engineering constraints. To use the same equipment to sterilize medical supplies, sludge, or other items at megarad dosages, the minimum dosage for the irradiator could exceed that required for the treatment. (This was the case in our tests using the Sandia Laboratories cesium sludge irradiator, where the minimum dose we could get was 30 krads.) Brynjolfsson (1973) indicated that the operating cost of a 10-MeV linear accelerator would be less than that for a cobalt or cesium irradiator, but the fruit probably would have to be processed in single layers instead of cartons.

Engineering studies are needed to establish the dosimetry for commercial irradiators with the capacity to treat 2 million pounds or more of a commodity per day at a minimum dose of 25 krads and a maximum of 75 to 100 krads and to insure that a fixed amount of gamma radiation will reach all of the commodity being treated, regardless of bulk density, type of commodity, or loading configuration. The system would have to be adjustable to permit treatment of the commodity at different dosages if other species of pest are present.

Additional dosage-mortality studies of each pest species infesting each commmodity may be required to confirm that quarantine security will result from irradiation under the conditions required to expedite treatment and minimize adverse effects on the commodity. Dosage-mortality studies may be required for each type of commercial irradiator, which may give different results depending on type of radiation (gamma or X-ray), radiation source, and loading configuration. Finally, cost-benefit and cost-effectiveness studies are needed to determine if the use of irradiation would be superior to the use of heat, cold, or other possible treatments.

REFERENCES

Baker, A. C.
1939. The basis for treatment of products where fruit flies are involved as a condition for entry into the United States. U.S. Dep. Agric. Circ. 551, 8 pp.

Balock, J. W.; Burditt, A. K., Jr.; and Christenson, L. D.
1963. Effects of gamma radiation on various stages of three fruit fly species. J. Econ. Entomol. 56: 42-46.

Balock, J. W.; Burditt, A. K., Jr.; Seo, S. T.; and Akamine, E. F.

BEST DOCUMENT AVAILABLE

1966. Gamma radiation as a quarantine treatment for Hawaiian fruit flies. J. Econ. Entomol. 69: 202-204.

Balock, J. W.; Christenson, L. D.; and Burr, G. O.
1956. Effect of gamma rays from cobalt-60 on immature stages of the oriental fruit fly [*Dacus dorsalis* Hendel] and possible application to commodity treatment problems. Proc. Ann. Meet. Hawaii. Acad. Sci., 31st, p. 18.

Benschoter, C. A., and Telich C. J.
1964. Effects of gamma rays on immature stages of the Mexican fruit fly. J. Econ. Entomol. 57: 690-691.

Beraha, L.; Ramsey, G. B.; Smith, M. A.; and Wright, W. R.
1959. Factors influencing the use of gamma radiation to control decay of lemons and oranges. Phytopathology 49(2): 91-96.

Brynjolfsson, A.
1973. Factors influencing economic evaluation of irradiation processing. *In* Factors Influencing the Economic Evaluation of Food Irradiation, pp. 13-35. Proceedings of a panel held in Vienna, 1971. International Atomic Energy Agency, Vienna.

Bughio, A. R.; Qureshi, Z. A.; and Mecci, A. K.
1969. Effects of gamma-radiation on eggs of *Dacus zonatus* (Saunders). Int. J. Radiat. Biol. 16: 183-192.

Burditt, A. K., Jr., and Seo, S. T.
1971. Dose requirements for quarantine treatment of fruit flies with gamma radiation. *In* Disinfestation of Fruit by Irradiation, pp. 33-41. Proceedings; Panel on the Use of Irradiation to Solve Quarantine Problems in the International Fruit Trade, Honolulu, Hawaii, 1970. International Atomic Energy Agency, Vienna.

Cavalloro, R., and Delrio, G.
1971. Biological effects of gamma radiation on the life stages of two fruit fly species. *In* Radionuclides in Ecosystems. Proc. Nat. Symp. on Radioecology, 3d, Oak Ridge, Tenn., vol. 2, pp. 1179-1190.

Dennison, R. A.; Grierson, W.; and Ahmed, E. M.
1966. Irradiation of Duncan grapefruit, pineapple and Valencia oranges and Temples. Proc. Fla. State Hortic. Soc. 79: 285-292.

Dollar, A. M.; Hanaoka, M.; McClish, G. A.; and Moy, J. H.
1971. Semi-commercial-scale studies on irradiated papaya. *In* Disinfestation of Fruit by Irradiation, pp. 137-156. Proceedings; Panel on the Use of Irradiation to Solve Quarantine Problems in the International Fruit Trade, Honolulu, 1970. International Atomic Energy Agency, Vienna.

Hatton, T. T., Jr.; Beraha, L.; and Wright, W. R.
1961. Preliminary trials of gamma radiation on mature Irwin and Sensation mangos. Proc. Fla. Mango Forum Ann. Meet., 21st, pp. 15-17.

Hossain, M. M., and Hamid, M. A.
1968. Irradiation preservation of certain tropical fruits. *In* A Comprehensive Report on IAEA/FAO Research Contract No. 361/R1/RB on Banana and Mango, AEDC/RB-9, 36 pp.

Lutz, J. M., and Hardenburg, R. E.
1968. The commercial storage of fruits, vegetables, and florist and nursery stocks. U.S. Dep. Agric. Agric. Handb. 66, 94 pp.

Macfarlane, J. J.
1966. Control of the Queensland fruit fly by gamma irradiation. J. Econ. Entomol. 59: 884-889.

Moshonas, M. G., and Shaw, P. E.
Flavor, aroma, and compostion of grapefruit products from fumigated and irradiated fruit. (Paper in progress.)

Pablo, I. S.; Manalo, Juanita A.; and Cardene, Victoria A.
1971. Sensory, chemical, and nutritional evaluation on the effect of ionizing radiation on mangos (*Mangifere indica*, Linn), Carabao variety. *In* Disinfestation of Fruit by Irradiation, pp. 101-111. Proceedings; Panel on the Use of Irradiation to Solve Quarantine Problems in the International Fruit Trade, Honolulu, 1970. International Atomic Energy Agency, Vienna.

Riov, J.
1971. 6,7-Dimethoxycoumarin in the peel of gamma-irradiated grapefruit. Phytochemistry 10: 1923

Seo, S. T.; Kobayashi, R. M.; Chambers, D. L.; Dollar, A. M.; and Hanaoka, M.
1973. Hawaiian fruit flies in papaya, bell pepper, and egg-plant: quarantine treatment with gamma irradiation. J. Econ. Entolmol. 66: 937-939.

Seo, S. T.; Kobayashi, R. M.; Chambers, D. L.; Steiner, L. F.; Lee, C. Y. L.; and Komura, M.
1974. Mango weevil: cobalt 60 gamma irradiation of packaged mangos. J. Econ. Entolmol. 67: 504-505.

Shipp, E., and Osborn, A. W.
1968. Irradiation of Queensland fruit fly pupae to meet quarantine requirements. J. Econ. Entomol. 61: 1721-1726.

Sreenivasan, A.; Thomas, P.; and Dharkar, S. D.
1971. Physiological effects of gamma radiation of some tropical fruits. *In* Disinfestation of Fruit by Irradiation, pp. 65-91. Proceedings; Panel on the Use of Irradiation to Solve Quarantine Problems in the International Fruit Trade, Honolulu, 1970. International Atomic Energy Agency, Vienna.

Thomas, A. C.
1975. The application of ionising radiation to the shelf life extension of mangos in South Africa. Republic of South Africa, Atomic Energy Board, Pelindaba, Pretoria, PEL-244, 15 pp.

Thomas, P., and Rahalkar, G. W.
1975. Disinfestation of fruit flies in mango by gamma irradiation. Curr. Sci. 44: 775-776.

U.S. Code of Federal Quarantine Regulations (revised).
1973. Title 7. Agriculture. Chapter III. Animal and Plant Health Inspection Service, U.S. Department of Agriculture. Part 319. Foreign Quarantine Notices. Subpart. Fruit and Vegetables.

☆U.S. GOVERNMENT PRINTING OFFICE: 1981—569-036/11C

BEST DOCUMENT AVAILABLE